# AN ASSESSMENT OF IMPULSE RADAR AS AN ICEBERG DRAFT MEASUREMENT TOOL

A REPORT PREPARED FOR C-CORE
BY: REMOTEC APPLICATIONS INC.
ST. JOHN'S, NEWFOUNDLAND

Contract Report

C-CORE Publication No. 82-8

November, 1982

C-CORE

CENTRE FOR COLD OCEAN RESOURCES ENGINEERING
MEMORIAL UNIVERSITY OF NEWFOUNDLAND
ST. JOHN'S, NEWFOUNDLAND, CANADA, A1B 3X5
TELEX 016 4794 TELEPHONE (709) 737-8354

The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial University of Newfoundland in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from government and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources in cold and ice frequented oceans.

## ABSTRACT

The potential use of impulse radar in iceberg draft measurement has been critically reviewed. The report includes a review of all pertinent theory and a description of a specific operational system developed by C-CORE. On theoretical grounds the airborne impulse radar system should be capable of sounding 250 meters of glacial ice, actual measurements to date have not exceeded 83 metres. It appears that the primary limitation on system performance may be the shape of a berg both above and below water.

## Acknowledgements

Dr. Ernest Reimer, the Leader of the Ice Properties Group at C-CORE commissioned REMOTEC Applications Inc. to prepare a report assessing impulse radar as a tool for measuring iceberg draft.

TABLE OF CONTENTS


| | PAGE |
|---|---|
| ABSTRACT | i |
| ACKNOWLEDGEMENTS | ii |
| TABLE OF CONTENTS | iii |
| LIST OF FIGURES | v |
| 1.0 INTRODUCTION | 1 |
| 1.1 The Problem | 1 |
| 1.2 Review of Present Draft Measurement Technique | 2 |
| 1.3 Proposed New Technique | 3 |
| 2.0 SOUNDING ICEBERGS USING IMPULSE RADAR - THEORETICAL CONSIDERATIONS | 5 |
| 2.1 General | 5 |
| 2.2 Dielectric Properties of Glacial Ice | 5 |
| 2.3 Dielectric Properties of Air and Sea Water | 8 |
| 2.4 Detection of Air-Ice and Ice-Water Interfaces | 8 |
| 2.5 Theoretical Penetration Capability of the 120 MHz System | 8 |
| 2.6 Iceberg Physical Characteristics Considerations | 9 |
| 2.7 Conclusion | 10 |
| 3.0 ICEBERG DRAFT MEASUREMENTS USING RADAR - A REVIEW | 11 |
| 4.0 DESCRIPTION OF OPERATIONAL SYSTEM | 17 |
| 4.1 Radar System | 17 |
| 4.2 Optional Camera System | 20 |
| 5.0 OPERATIONAL CONSIDERATION | 21 |
| 5.1 Platform Deployment | 21 |
| 5.2 Personnel Requirements | 21 |
| 5.3 Suggested Data Collection Procedure | 22 |
| 5.4 Helicopter Offshore Range Consideraton | 23 |
| 6.0 EVALUATION AND CONCLUSIONS | 25 |
| REFERENCES | 27 |
| APPENDIX A - A DETAILED THEORETICAL DESCRIPTION OF THE PRINCIPLES OF SOUNDING A MATERIAL USING RADAR | 31 |
| A-1 Comparison Between Impulse Radar and Pulsed C.W. Radar | 31 |
| A-2 Impulse Radar Sounding | 33 |
| APPENDIX B - ICEBERG PROFILING: A DELINEATION OF FAVOURABLE AND UNFAVOURABLE CONDITIONS | 39 |

B-1 General ..... 39

B-2 Size ..... 39

B-3 Shape ..... 42

B-4 Structural Featuses ..... 43

B-5 Temperatuse ..... 43

APPENDIX C - SPECIFICATIONS OF THE INSTRUMAR MODEL 100, 120 MHz AIRBORNE IMPULSE RADAR SYSTEM ..... 45

## LIST OF FIGURES


| | | Page |
|---|---|---|
| Figure 3.1 | Profile of an Iceberg Shaped Like a Tilted Pyramid, Obtained Using a 120 MHz Airborne Impulse Radar System ..... | 16 |
| Figure 4.1 | Block Diagram of Impulse Radar System ..... | 18 |
| Figure A.1 | Comparison of the Transmitted Waveforms From an Impulse and a Pulsed CW Radar ..... | 32 |
| Figure B.1 | Diagram of Ray Paths for Cubic and Spherical Iceberg Models ..... | 40 |

# 1.0 INTRODUCTION

## 1.1 The Problem

Icebergs off the east coast of Canada pose a serious environmental threat to offshore hydrocarbon exploration and development. They are considered the single most serious obstacle facing development in the Labrador offshore (Duval, 1975) and the most dramatic phenomena associated with the Grand Banks area (Blenkarn and Knapp, 1969). Icebergs are composed of very hard glacial ice and the average iceberg off the Labrador coast weighs about one million tonnes (Duval, 1975). Almost ninety percent of an iceberg is underwater. Iceberg grounding on the sea bottom appears to occur all along the coast of Labrador and in the Grand Banks, although a quantitative rate of grounding and scouring in any given area is yet to be established. A collision of even a small iceberg with a surface platform or vessel or a seabed installation is quite possible and could result in a catastrophic disaster.

Because of the randomness of the above water portion an iceberg shape and the lack of knowledge concerning the relationship between the above water parameters and the iceberg draft, it is almost impossible for an offshore operator to assess the hazard to his seabed installation. Thus a need exists for a reliable technique to measure the draft, both from a real time operational and a research viewpoint.

## 1.2 Review of Present Draft Measurement Technique

The only draft measurement technique currently used operationally was initially developed by Benedict (1973). The acoustic technique involves lowering a sidescan towfish vertically through the water from a ship which must be located within 200 metres of the iceberg. The towfish receives echoes off the side of the iceberg until the bottom of the iceberg is passed. The depth of the towfish is monitored and the depth at which returns are no longer received is considered to be the maximum draft of the iceberg. Normally up to four measurements are made at different points around the iceberg.

There are significant inadequacies in this technique. It can only be employed in low sea states (up to about Beaufort 2) and requires a ship to maintain a position dangerously close to a large and potentially unstable body for periods of 30 minutes or more. The technique is slow in that it can take an hour to complete the measurements. The ship's speed combined with the probable distance between icebergs (in the order of kilometers) necessitates long periods to obtain a signficant number of draft measurements from different icebergs. The requirement of having a ship, equipment and a specially trained crew totally committed for a long period of time makes this an expensive operation as well. Finally, the inability to determine accurately the location of the towfish and the occurence of excessive wire angles due to unavoidable ship movements cause the data to have potentially very large inaccuracies.

## 1.3 Proposed New Technique

Impulse radar systems are active sensors that transmit short duration pulses of electromagnetic energy having a relatively wide frequency bandwidth, and receive the corresponding reflected pulses from interfaces where there are marked changes in dielectric properties. Unlike many other remote sensors, they can be used to probe beneath the surface of a medium and are thus sometimes referred to as "ground penetrating" radars. Their ability to penetrate various media has led to the development of several subsurface profiling applications. In operational use since 1970, impulse radar systems have been develloped in the HF, VHF, S-band, and X-band frequency ranges. Generally speaking, lower frequencies provide better penetration at the expense of coarser resolution.

Originally developed as a shallow subsurface profiler for geophysical applications (Morey, 1974), impulse radars have since been used for profiling glaciers and ice shelves (Watt and Wright, 1981); measuring sea ice and freshwater ice thickness (Campbell and Orange, 1974; Chizhov Glushnev and Slutsker 1977); mine profiling in coal, salt and dolomite; studying permafrost (Annan and Davis, 1976); mapping buried chemical waste disposal sites (Horton et al., 1981); detecting oil layers under ice (Mann, 1979; REMOTEC, 1981) and depth profiling of peat deposits (REMOTEC, 1982).

The electrical properties of ice are well documented, and fresh water ice from polar sources is fairly transparent to radar waves. This led to the use of electromagnetic profilers such as

pulsed CW (continuous wave) and impulse radar systems to measure the thickness of glaciers, ice shelves and icebergs.

This document provides a comprehensive description of a 120 MHz airborne impulse radar system and an assessment of its operational feasibility as an iceberg draft measurement device. The capability of quick deployment on a helicopter, the speed at which a draft measurement can be made, and the potential for obtaining a large data base in a short time frame (helicopter and measurement speed) make this an attractive alternative to the current technique. In addition the hazard is considerably reduced and sea state conditions are not restrictive.

The particular system described here was developed by the Centre for Cold Ocean Resources Engineering for Ice Thickness measurement and is now offered as a product of INSTRUMAR Limited on a rental or purchase basis. REMOTEC Applications Incorporated has considerable experience with the field operation of the equipment and can supply trained operators to undertake field programs.

## 2.0 SOUNDING ICEBERGS USING IMPULSE RADAR - THEORETICAL CONSIDERATIONS

### 2.1 General

Impulse radar systems, unlike pulsed CW systems (which transmit a pulse at one carrier frequency), transmit a carrier free, very short broadband pulse. The pulse shape allows measurement within the pulse length, and this effectively increases the time scale resolution. The principles of sounding a material are essentially the same for both impulse and pulsed CW systems. A pulse is transmitted into a medium and energy is reflected whenever an abrupt discontinuity occurs in the dielectric properties (eg., at an air/ice interface, at an ice/water interface, or at a discontinuity within the ice). The time delay from transmission to reception of this reflected energy, and a knowledge of the dielectric properties of the medium of interest, are used to identify discontinuities within the medium and determine its thickness. A detailed theoretical description of the principles of sounding material using radar is given in Appendix A. The theoretical equations presented there are applied here to demonstrate the feasibility of sounding icebergs by impulse radar.

### 2.2 Dielectric Properties of Glacial Ice

The dielectric constant determines the velocity of propagation in a material and the degree of transmission and reflection at the interface between two materials. Pure

polycrystalline ice has a dielectric constant of 3.17 ± 0.07 in the frequency range of about 1 to $10^4$ MHz and is effectively independent of the temperature of the ice (Evans, 1965). The dielectric properties are strongly influenced by the inclusion of materials such as air, water and salt.

It can be shown from the physical properties of ice that brine (concentrated salt water) will not infiltrate icebergs as they drift in the ocean. Kovacs and Gow (1975) report that brine does not infiltrate glacial ice of a density greater than 0.82 Megagrams/cubic metre ($Mg/m^3$) because beyond this density there are no interconnected pores in the ice. The iceberg density of 0.89 $Mg/m^3$ reported by Smith (1931) indicates that brine will not interfere with the profiling of icebergs. Radar measurements by Goodman, Outcalt and Narod (1977) confirm that brine permeates into the ice less than 3 cm.

Actual measurements (Robin, Evans and Bailey 1969, and Swithinbank, 1977) on Antarctic glaciers showed that a dielectric constant of 3.2 appeared to be appropriate. Rossiter and Gustajtis (1977) obtained good correlation between sonar and radar measurements using a dielectric constat of 3.2, although they noted that an error of ±0.3 was possible, due to the small size of the iceberg. Kovacs (1977a) found that a dielectric constant of 3.5 was more appropriate for an ice island in the Beaufort Sea. This particular ice, however, was known to have internal impurities. It is concluded therefore that a dielectric constant of 3.2 seems appropriate for iceberg ice. A further verification can be made in future tests.

To determine the attenuation rate and hence the maximum iceberg thickness that can be sounded the value of the loss tangent (tan $\delta$) is required. This valule is determined by the ratio of the real part to the imaginary part of the complex permittivity. The loss tangent of pure ice at 0°C is given by the equation:

$$\tan \delta = 0.2/f \qquad \text{dB m}^{-1},$$

where f is the frequency in megahertz in the range from 0.1 to 500 MHz (Evans, 1965). This gives a value of 0.00167 at 120 MHz. An increase will occur if impurities are present and a decrease will result if the temperature is lower (to about 0.01/f at -60°C).

Using the equation for attenuation given in Appendix A at 0°C the attenuation rate is 0.03 dB/m. Swithinbank (1977) found that the attenuation rate in Antarctic ice shelves was less than 0.04 dB/m. Rossiter, Narod and Clarke (1979) reported being able to sound an effective iceberg thickness of 144 metres (based on observations of multiple reflections from a 72 m thick tabular iceberg). The return corresponding to 144 m was just above the background noise level. An attenuation rate of 0.05 dB/m gives a maximum thickness measurement capability of 140 metres. It is assumed therefore, that an attenuation rate of 0.05 dB/m is a reasonably conservative rate to use in calculating the maximum iceberg thickness that can be measured. This corresponds to a loss tangent of 0.31/f or 0.00257 at 120 MHz.

## 2.3 Dielectric Properties of Air and Sea Water

The dielectric constant of air is about 1.0006, which is normally approximated with the dielectric constant of free space, ($\varepsilon = 1$). The dielectric constant of sea water is 81 in the VHF to UHF frequency range. The loss tangent of air is negligibly small. The loss tangent of seawater is very large: $\tan \delta = 7.40$ and the attenuation at 120 MHz calculated from this value is 353 dB/m. Obviously radar signals will not penetrate far into seawater.

## 2.4 Detection of Air-Ice and Ice-Water Interfaces

Using the equations provided in Appendix A the reflection coefficient at the air-ice interface will be 0.08 while the two way transmission coefficient will be 0.85. These values should be quite sufficient to allow the air-ice interface to be detected and still allow sufficient energy to be transmitted into and out of the ice. (This transmission coefficient is taken into account in determining the penetration capability in Section 2.5)

The reflection and (one way) transmission coefficient at the ice water interfaces will be 0.45 and 0.55, respectively. These figures show that the ice-water interface should show up very strongly, with transmission through it being considerably reduced.

## 2.5 Theoretical Penetration Capability of the 120 MHz System

To evaluate the ability of the 120 MHz impulse radar system to penetrate icebergs the performance figure of the system

(115 dB) is compared to the propagation and antenna losses using the radar range equation as applied to airborne impulse radar sounding by Kovacs and Grow (1975) and Butt and Gamberg (1979). The maximum iceberg thickness that could be penetrated (calculated using Equation A.4 with a helicopter flying height of 10 m (30') and an attenuation rate of 0.05 dB/m (Section 2.2)), is 250 m. This value was calculated for ideal conditions of reflection, a large smooth horizontal reflecting surface that may be found, for example, on a tabular berg. The maximum iceberg thickness that could be penetrated, calculated for less ideal conditions of reflection using Equation A.5 and the same parameters, is 115 m. The maximum penetrable thickness may be increased by contact between the antenna and the iceberg, due to a coupling of the antenna to the ice medium. It is estimated that this may increase the penetration by 25 m. The profile obtained when the antenna is in contact with the iceberg is non-moving (static) in nature, and this may make it more difficult to separate the bottom reflection from reflections off the sides of the berg. Best results can be expected from larger icebergs.

## 2.6 Iceberg Physical Characteristics Considerations

Appendix B provides an in-depth analysis of the iceberg size limitations and the effect of the above surface shape on iceberg sounding. In addition the effects of internal structural features and iceberg temperature are also considered.

The size analysis, based on simple models, indicates that icebergs ranging in mass from 0.024 to 10 million tonnes can be

sounded. It is also shown that less than 5 percent of the icebergs off the Labrador Coast exceed this maximum limitation.

Tabular, blocky and large domed icebergs are demonstrated to be more favourable for sounding. These types will probably present the maximum drafts in a given size class.

Finally, it is indicated that internal structural features and warm iceberg temperatures will probably not present a sounding problem. It is emphasized that these results are based on limited quantitative data and simple models. Actual limitations can only be clearly defined through considerable operational experience.

## 2.7 Conclusion

It is clear that it is technically feasible to sound icebergs using impulse radar based on the dielectric properties considerations. The power loss calculations indicate that the proposed system should be able to sound icebergs having thicknesses greater than 100 metres and potentially up to 250 metres. Analyses of various iceberg physical characteristics indicated that the maximum iceberg size will probably not present a problem at least off the coast of Labrador. Certain above surface shapes may present some problems. A more exact determination of the sounding limitations can only be derived through operational experience.

## 3.0 ICEBERG DRAFT MEASUREMENTS USING RADAR - A REVIEW

Impulse and pulse CW radars have been used frequently for glacier thickness measurements over the last number of years. Both have also been employed for sounding icebergs although only to a limited extent. This section provides an historical review of the work to date.

Swithinbank (1977) reported results using a 60 MHz pulsed CW radar system with a pulse length of 0.3 microseconds ( s) and a peak pulse power of 1.2 kilowatts (kW). This system was installed on a number of different aircraft and successfully sounded both glaciers and very large tabular icebergs in the Antarctic.

In 1977 Goodman, Outcalt and Narod published findings using a helicopter mounted 840 MHz pulsed CW radar with a pulse length of 96 nanoseconds (ns) and a root-mean-square (RMS) peak power of 4.1 kW. At least one iceberg thickness was considered to be measured successfully although no verification data were available. Soundings were made while the helicopter hovered above the iceberg and actually touched down on it. Goodman, Outcalt and Narod also suggest that it may be possible to reconstruct the underwater shape of an iceberg using a technique employed to enhance seismic records. They demonstrated the technique using a model of an iceberg radar echo.

Kovacs (1977a and 1977b) successfully used a ground based impulse radar to sound a very large tabular iceberg in Antarctica and an ice island (about 24 metres thick) in the Beaufort Sea. The centre frequency and the bandwidth was 100 MHz. Kovacs

concluded that it is possible to obtain information on mesoscale bottom relief and internal layers as well as thickness data. He also recommended tests using an airborne configuration.

Rossiter and Butt (1979) utilized an airborne impulse radar system successfully, this time with a 300 MHz centre frequency, to sound an ice island in the Beaufort Sea. The ice island was shown to have a thickness varying from 10 to 30 metres. The system was deployed on a de Havilland Twin Otter flying at a speed of 140 knots and at an altitude of 80 metres.

An 80 MHz (centre frequency) impulse radar system was tested for its iceberg sounding capability by Rossiter and Gustajtis (1978 and 1979) in 1977. The system had a bandwidth of about 100 MHz, a pulse length of 20 ns. and a peak power into the antenna of 53 watts. It was a ground based configuration but was mounted on a helicopter for this test and flown repeatedly over the target at low speed. The antenna was slung 6 metres below the helicopter which was flown about 15 metres above the iceberg. The sidescan draft measurement technique described in Section 1.2 was used to verify the draft measurement. Only one small domed iceberg was sounded. The same draft (18 metres) was measured using both techniques. The conclusions from this work were that airborne radar showed considerable promise as a quick, safe and accurate means of sounding icebergs; that the technique might be easier to apply to larger icebergs because of the multiple reflection problem which might occur in smaller icebergs; and that the technique might be most useful for relating the above-water shape of icebergs to their draft on a statistical basis.

The authors also made reference to the possibility of being able to obtain underwater shape using the technique described by Goodman, Outcalt and Narod (1977).

In 1978, the same system as described in the preceeding paragraph was used to sound nine small and medium sized icebergs of various shapes off the Labrador coast using the same airborne configuration (Rossiter, Narod and Clarke, 1979). At the same time it was compared with the pulsed system used by Goodman, Outcalt and Narod (1977) and previously described. There was general agreement between the results from the two radar systems although the impulse radar far outperformed the pulsed CW system. (From the report only two draft measurements were provided for the pulsed CW system.) Iceberg drafts ranging from 28 to 65 m were measured and no alterenate technique for verification was employed. The height to draft ratios did, however, fall within the expected ranges. Of nine icebergs, seven were considered to be sounded successfully by the impulse radar. Of the other two, one had only a faint bottom echo and on the other multiple reflections made the draft measurement questionable. The poorer performance of the pulsed CW radar was said to have been due probably to its much poorer resolution and considerably lower scan rate.

The discussion and conclusions of this last work are important as they are based on the only significant sampling known to date. The authors suggested that it should be possible to use radar to sound the largest icebergs encountered in the Arctic waters with the major limitation being internal scattering

due to irregular iceberg shapes. They also pointed out that until at least two different techniques can be employed at the same time to measure a number of iceberg drafts it will be impossible to know how reliable the radar measured drafts of individual icebergs are. Because of the speed at which measurements can be made the authors suggested that the technique could be used to obtain statistical data from a large number of icebergs. In this case the error associated with one individual measurement may not be critical.

A review of this last work was undertaken by Kovacs (1979). He agreed with the need for further data collection. He also identified the need for further instrument development (more directional antennas, higher transmitter power, and higher receiver gain) and improved data processing techniques (real time signal enhancement and background noise removal).

In a discussion of the same work Brooks and Sabins (1979) agreed that airborne radar could provide an iceberg draft statistical data base. They also suggested that it should be utilized as a research rather than an operational tool because of the uncertainty that the maximum draft is being seen. Reflection was noted as a possibly significant problem in the relatively small irregular shaped Arctic icebergs. They concurred that more field work is required to delineate fully the feasibility of the technique.

The only other known attempt to sound icebergs off the Labrador coast was undertaken in 1981 (Bazeley, 1982). The airborne impulse radar used is the one described in this

document. The pulse length was 10 ns and the peak transmit power was 50 watts. (A detailed description of the system is given in Section 4.0.) The iceberg was grounded and hydrographic information was used to verify the measured draft of 83 metres. Figure 3.1 shows the radar data for this iceberg. Because of the frequency insensitivity of ice, except for a small increase in propagation loss, this system should have essentially the same performance capability as the 80 MHz system described earlier.

Butt (1982) reports that realtime background noise removal is now available on the 120 MHz system. Work towards boosting the power into the antenna system is also now in progress.

In summary, research to date clearly indicates the considerable potential of radar for sounding Arctic icebergs. There is a lack of research and development work with pulsed CW systems. Airborne impulse radar, however, operating over the frequency range of 80 to 300 MHz is clearly attractive in view of its high success rate in tests to date. There is a general consensus among researchers that more sampling with alternate draft verification techniques is required in order to delineate fully the capabilities of impulse radar. There is also general agreement that it is a potentially attractive tool for obtaining a large statistical data base. The potential for measurement of the actual underwater shape warrants investigation because of its enormous benefits.

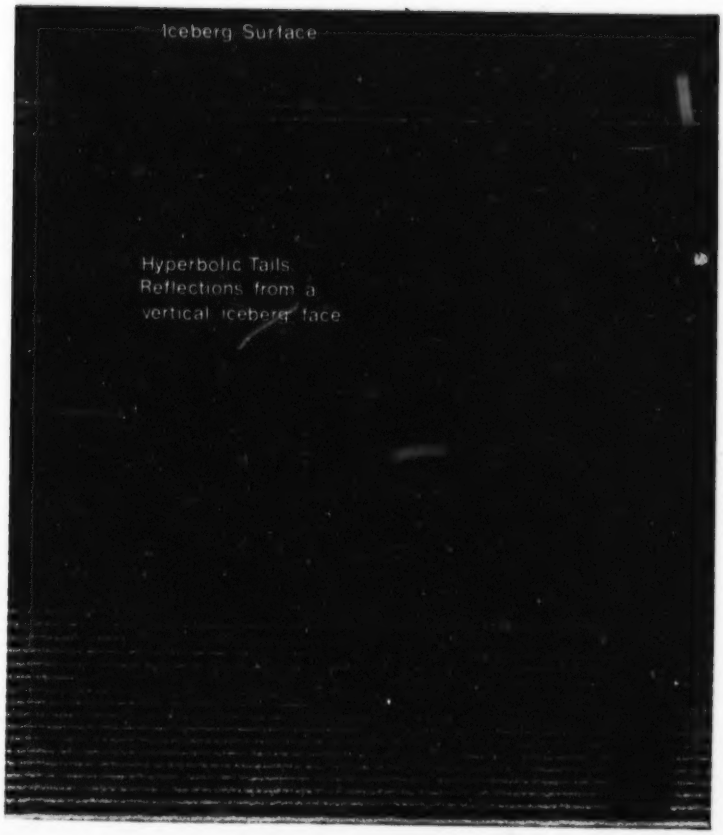



Figure 3.1 Profile of an Iceberg Shaped Like a Tilted Pyramid, Obtained Using a 120 MHz Airborne Impulse Radar System

## 4.0 DESCRIPTION OF OPERATIONAL SYSTEM

### 4.1 Radar System

The system proposed for profiling icebergs is the INSTRUMAR Model 100 Airborne Impulse Radar, which operates with a 120 MHz centre frequency. The time scale resolution of the system, calculated from the pulse length of 10 ns and from the propagation velocity in iceberg ice, is 0.9 m. The ability to resolve detail within the pulse length provides an actual range resolution of around 0.3 m. The precision therefore of an individual thickness measurement on an iceberg is about $\pm 0.5$ m.

The major components of the impulse radar system are: the antenna, the control unit, the tape recorder and the grey scale plotter (Figure 4.1). The technical specifications and description of the system provided by INSTRUMAR are included as Appendix C.

The system's single antenna was designed to be mounted beneath a helicopter by means of a frame attached to the helicopter's cargo hook. Alternatively the antenna may be mounted on a fixed wing aircraft if the inside of the lower fuselage is accessible. The antenna is shielded to minimize reflection and 'ringing' from the metal fuselage and has a built in radar altimeter. The output of the altimeter can be recorded on tape to allow the removal of any altitude variation in the data. The antenna contains a resistively loaded dipole element that radiates and receives the radar impulses. The antenna also contains the transmitting and receiving electronics.

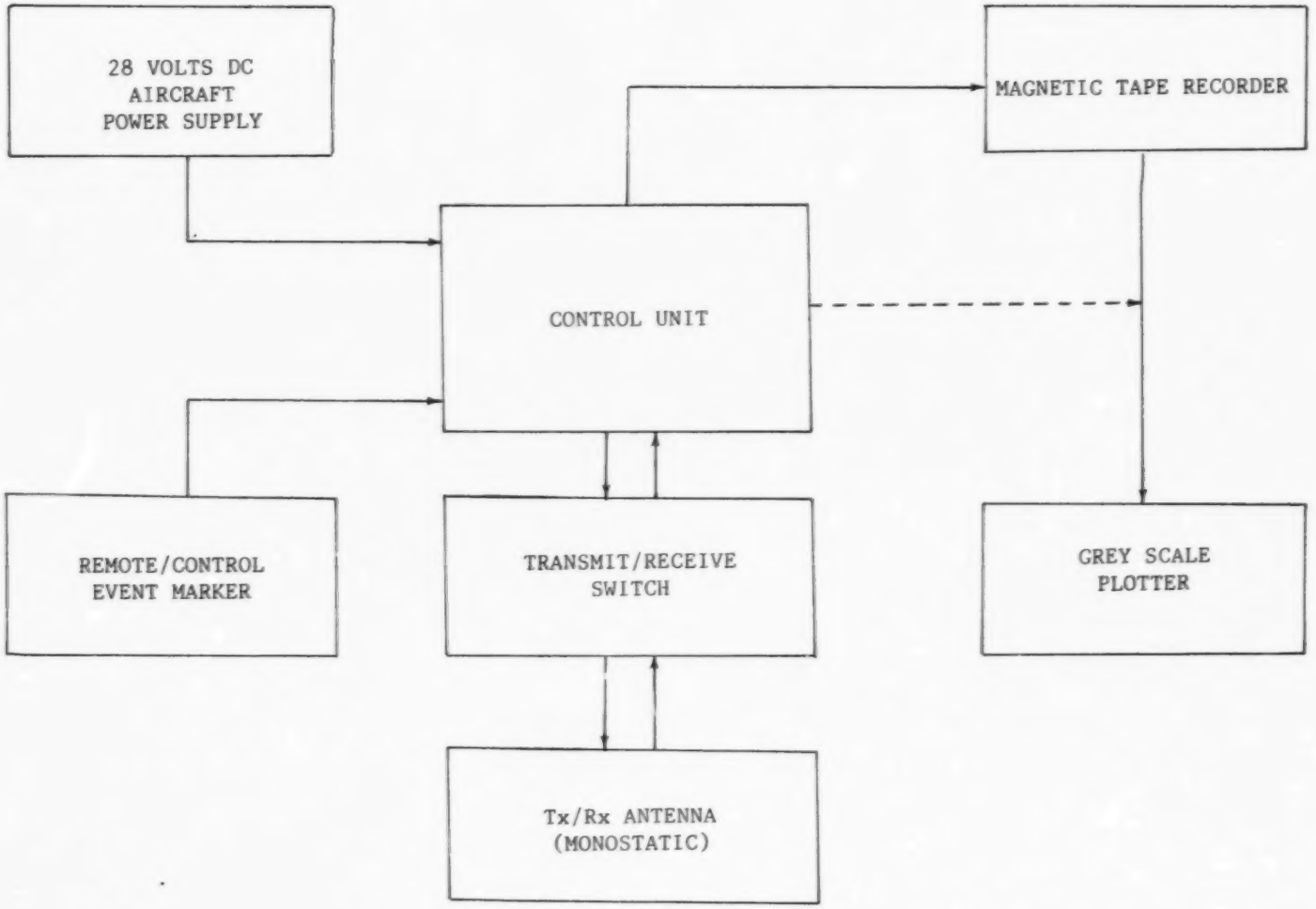



FIGURE 4.1 BLOCK DIAGRAM OF IMPULSE RADAR SYSTEM

The receiving electronics include sampling equipment used to shift the VHF signal into the audio frequency range 0-5 KHz) so that it can be printed on a chart recorder and/or recorded on analog magnetic tape using an instrumentation recorder. The reduction in frequency is performed by sampling consecutive radar frequency scans to construct an audio frequency replica. The impulse radar pulse repetition frequency (P.R.F.) is about 131 KHz. A total of 16,384 radar frequency scans are used to construct a single replica scan, thus reducing the scan rate to 8 replica scans per second. Each of the radar frequency scans is sampled at a single point. The sample point progresses along the time axis for each consecutive radar frequency scan, resulting in a stretched time axis in the replica scan. The actual frequency reduction depends on the length of time (time window) that is sampled in the radar frequency scan. For example, a 120 MHz bandwidth wave in a 2880 ns window would be reduced to about 2.8 KHz in the replica scan assuming a scan rate of 8 scans/sec. The sampled down signal can be recorded onto a four channel instrumentation tape recorder, along with a scan ramp (trigger) and a digitizing clock. The altimeter data may also be recorded. The recorder presently in use with the INSTRUMAR system is the Racal Store 4D recorder because it allows remote tape operation from the radar control unit. The control unit, in addition to operating the recorder, also regulates the transmitting and receiving functions of the antenna as well as controlling the time window length, the time varying gain, the graphic plotter, and the cathode ray tube (C.R.T.) display. The C.R.T. display,

built into the control unit, gives an amplitude display of the radar returns to facilitate the selection of the proper gain levels. The graphic plotter used with the INSTRUMAR system is a Minifax grey scale plotter that uses intensity modulated line traces to make a plot of the radar returns. The maximum scan rate for the Minifax is 16 scans/second. This is sufficient for a real time plot of the iceberg profile. The Minifax is used because of its small size, weight and power requirements, but it gives a rough quality printout. To obtain a high quality printout the signals can be recorded on tape and printed out in the lab using a 8 level grey scale printer such as the Honeywell Visicorder.

## 4.2 Optional Camera System

An optional camera mount produced by INSTRUMAR can also be used to provide crude aerial stereophotography of the iceberg being sounded. The mount is designed for deployment in a small helicopter and can be mounted in the same helicopter along with the impulse radar system. No special installation work is required. Either a 35 or 70 mm camera can be utilized.

## 5.0 OPERATIONAL CONSIDERATIONS

### 5.1 Platform Deployment

The INSTRUMAR 120 MHz impulse radar has been mounted in small helicopters, the Bell 206B and 206L, as well as a fixed wing aircraft, the tri-turbo DC-3. The compactness and portability of the unit allows considerable flexibility for installation on a variety of other airborne platforms. The antenna size and the requirement for mounting outside and underneath the fuselage are the major limiting factors. The system is designed to run off 28 VDC normally supplied in any airborne platform.

The system scan rate required for profiling icebergs is 8 scans/second. Based on experience with sea ice profiling the estimated upper limit of forward movement is about 1 metre per scan. This implies a maximum, horizontal speed of 15 knots. The unit, therefore, must be mounted on a helicopter.

During operation, the control unit, instrumentation recorder (if required) and the graphic plotter are arranged in the rear seat of the helicopter. The antenna normally is mounted outside the helicopter underneath the passenger compartment.

### 5.2 Personnel Requirements

Normally, two people are required during an actual measurement program. One person operates the radar system and the recording units in the rear of the helicopter, while the other person, acting as an observer, is required to annotate the

features and log the flights over the icebergs. The observer can also operate the optional camera system described in Section 4.0.

5.3 Suggested Data Collection Procedure

Once an iceberg is located one should fly over it slowly in a "X" pattern, with the two lines in the pattern being perpendicular to each other. One should fly over each line twice with the second pass being in the opposite direction. This results in a total of four passes over the iceberg. The altitude at which one flies above the iceberg should be as low as possible; 10 metres should be the maximum.

If the iceberg is of sufficient size, has a large enough landing area, looks reasonably stable and the pilot is in agreement, a touchdown should be attempted. The period of the landing would be very short (in the order of a minute) with the pilot maintaining full takeoff power. This will allow maximum radar penetration and may help insure that the maximum drafts of the layer icebergs are being detected. It should be possible to complete an entire sounding operation within a fifteen minute period. Once the radar measurements are completed, if stereophotography is to be obtained, the helicopter will have to increase its altitude to that required for the particular iceberg (from about 200 metres to a maximum of about 1000 metres). One pass can then be made directly over the iceberg to obtain the photographs.

## 5.4 Helicopter Offshore Range Consideration

If the impulse radar is to be used as an adjunct to offshore drilling operations, and is to be mounted on the large helicopters servicing the offshore platforms, there should be no problem in obtaining draft data from all the icebergs within the area around the platform. In this situation flying range will not be a limitation.

If the system is to be deployed on a separate helicopter, range limitation may need to be considered. Considering the helicopter size requirement for the system a Bell 212 or its equivalent would be quite adequate. Large helicopters such as the Sikorsky-61 would be extremely expensive and much larger than required. For example, a Bell 212 operating from a coastal base probably can fly offshore 50 to 60 nautical miles and operate for up to an hour in a specific area before it has to return. This should be quite adequate to sound four to five closely spaced icebergs. If the area of interest is much larger, or further offshore, or if the number of icebergs to be sounded is excessive and if in the two latter cases an offshore platform cannot be used for refueling purposes, then alternatives must be considered. These could include multiple flights, the use of a larger helicopter to extend the range of operatitons, or the use of a ship equipped with a helicopter pad and refueling capability as an operational base. Hence, it is seen that the method of deployment will be highly dependent on a variety of factors. These need careful consideration to ensure the work is undertaken in the most cost effective manner.

If the radar is to be used as a research tool to obtain a large data base a very large area may have to be covered. In this case the use of a ship based operation may have to be considered. The main advantage in this case of the radar technique over the sidescan technique is the speed at which data can be collected.

## 6.0 EVALUATION AND CONCLUSIONS

The theoretical analysis, previous results, and operational considerations clearly demonstrate that the 120 MHz impulse radar system has the potential of being an attractive cost effective alternative to the current iceberg draft measurement technique. As a research tool it should be able to provide a very large data base within a very short time. Thus it reduces costs and allows for earlier opportunities to assess the iceberg draft problem properly. As an operational tool, if suitably deployed, it may provide a faster and less expensive assessment of the ongoing iceberg hazard to an offshore platform. The option of providing detailed above surface iceberg shape and reasonably accurate detailed dimensional information at a minimal additional cost add considerably to the attractiveness of the technique.

Because of the limited amount of draft verification data obtained to date, it is suggested that a small verification program be launched using an alternate measurement limit. Once this is completed successfully, the system can be considered fully operational.

The possibility of being able to derive the underwater shape of an iceberg should also be investigated. This is important in determining the disposition of the forces exerted on a drilling platform in a collision with an iceberg.

## REFERENCES


Annan, A.P. and J.L. Davis, (1976) "Impulse Radar Sounding in Permafrost", Science, Vol. 11, No. 4, 1976, pp. 383-394.

Bazeley, David P. (ed.), (1982), "Impulse Radar Applications", C-CORE News, Vol. 7, No. 2, June, 1982.

Benedict, C. Peter, (1973) "Underwater Profiling of Icebergs", Proceedings of Second International Conference on Port and Ocean Engineering Under Arctic Conditions, Reykjavik, Iceland, August 1973, pp. 601-607.

Blenkarn, K.A. and A.E. Knapp, (1969), "Ice Conditions on the Grand Banks", Ice Seminar, The Petroleum Society of the C.I.M., Calgary, Alberta, May 1968, C.I.M.M. Special Vol. 10, 1969.

Brooks, L.B., and F.F. Sabins, (1979) "Discussion of 'Airborne Radar Sounding of Arctic Icebergs' by J.R. Rossiter, B.B. Narod and G.K.C. Clarke", Proceedings of the Fifth International Conference on Port and Ocean Engineering Under Arctic Conditions (POAC 79), Trondheim, appended to paper reviewed, August 13-17, 1979.

Butt, Kenneth A., (1982) personal communication.

Butt, K.A. and J.B. Gamberg (1979) "Technology of an Airborne Impulse Radar" Proceedings of the International Workshop on the Remote Estimation of Sea Ice Thickness, St. John's, Sept. 25-26, 1979, C-CORE Publication No. 80-5 pp. 385-412.

Campbell, K.J. and A.S. Orange, (1974) "A Continuous Profile of Sea Ice and Freshwater Ice Thickness by Impulse Radar", Polar Record, Vol. 17, No. 106, January 1974, pp. 31-41.

Chizhov, A.N., V.G. Glushnev, and B.D. Slutsker, (1977) A Pulsed Radar Method of Measuring Ice Cover Thickness", Meteorologiya i Gidrologiya, No. 4, 1977, VDC 556. (042+535.5).

Duval, B.C., (1975) "Exploratory Drilling on the Canadian Continental Shelf, Labrador Sea", Offshore Technology Conference, May 1975, OTC-2155.

Evans, S., (1965) "Dielectric Properties of Ice and Snow - A Review", Journal of Glaciology Vol. 5, pp. 773-729.

Goodman, R.H., E. Outcalt, and B.B. Narod, (1977) "Radar Techniques in the Measurement of Floating Ice Thickness", Proceedings of the Fourth Canadian Symposium on Remote Sensing, Quebec City, May 1977, pp. 459-468.

Horton, K.A., R.M. Morey, L. Isaacson, R.H. Beers (1981) "The Complementary Nature of Goephysical Techniques for Mapping Chemical Waste Disposal Sites: Impulse Radar and Resistivity", The Second National Conference on Managemnt of Uncontrolled Hazardous Waste Sites, Washington, D.C. Oct. 28-30, 1981.

Kovacs, Austin, (1977a) "Iceberg Thickness Profiling", Proceedings of the Fourth International Conference on Port and Ocean Engineering Under Arctic Conditions, St. John's, Sept. 26-30, 1977, pp. 556-567.

Kovacs, Austin, (1977b) "Iceberg Thickness Profiling and Crack Detection", Proceedings of the First International Conference on Iceberg Utilization, Ames, Vol. 1, Oct. 2-6, 1977, pp. 131-145.

Kovacs, Austin, (1979), "Review of 'Airborne Radar Sounding of Arctic Icebergs' by J.R. Rossiter, B.B. Narod and G.K.C. Clarke", Proceedings of the Fifth International Conference on Port and Ocean Engineering Under Arctic Conditions (POAC 79) Trondheim, appended to paper reviewed, August 13-17, 1979.

Kovacs, A. and A.J. Gow, (1975) "Brine Infiltration in the McMurdo Ice Shelf, McMurdo Sound, Antarctica", Journal of Geophysical Research, Vol. 18, No. 15, pp. 1957-1961.

Mann, J., (1979) "Detection of Oil Trapped Under Ice Using Impulse Radar", APOA Report No. 119.

Morey, R.M., (1974) "Continuous Subsurface Profiling by Impulse Radar", Proceedings of Engineering Foundation Conference on Subsurface Exploration for Underground Excavation and Heavy Construction, American Society of Civil Engineers, New York, 1974, pp. 213-232.

Morey, R.M. (1975) "Airborne Sea Ice Thickness Profiling Using an Impulse Radar", Contract Report for U.S. Coast Guard by Geophysical Survey Systems Inc. CG-D-178-75, 32 pp.

REMOTEC Applications Inc., (1981) "Laboratory Experiments in the Detection of Oil Under Ice", Contract Report, Environmental Protection Service, Environment Canada.

REMOTEC Applications Inc., (1982) "The Use of Impulse Radar Techniques for Depth Profiling of Peat Deposits", Draft Contract Report, National Science and Engineering Research Council, Canada.

Robin, G., S. Evans and J. Bailey, (1969) "Interpretation of Radio Echo Sounding in Polar Ice Sheets", Phil. Trans. R. Soc. Lond. A, 265, 437.

Rossiter, J.R., and K.A. Butt, (1979) "Remote Estimation of the Properties of Sea Ice, Beaufort Sea Field Trip Report - March 1979", C-CORE Data Report 79-9, 36 pp.

Rossiter, J.R., and A. Gustajtis, (1979) "Determination of Iceberg Underwater Shape with Impulse Radar", Desalination, 29, pp. 99-107.

Rossiter, J.R., B.B. Narod, and G.K.C. Clarke, (1979) "Airborne Radar Sounding of Arctic Icebergs", Proceedings of the Fifth International Conference on Port and Ocean Engineering Under Arctic Conditions (POAC 79), Trondheim, August 13-17, 1979, pp. 289-305.

Smith, E.H., (1931) "The Marion Expedition to Davis Strait and Baffin Bay", U.S. Treasury U.S. Coast Guard Bulletin, volume 10, part 3, Report of the International Ice Patrol Service in the North Atlantic Ocean, 221 pp.

Swithinbank, C., (1977). "Remote Sensing of Iceberg Thickness", Proceedings of the First International Conference and Workshop on Iceberg Utilization, Ames, Oct. 2-6, 1977, pp. 100-107.

Watts, R.D. and D.L. Wright, (1981) "Systems for Measuring Thickness of Temperate and Polar Ice from the Ground or from the Air", Journal of Glaciology, Vol. 27, No. 97, pp. 459-469.

# APPENDIX A

## A DETAILED THEORETICAL DESCRIPTION OF THE PRINCIPLES OF SOUNDING A MATERIAL USING RADAR

### A.1 Comparison Between Impulse Radar and Pulsed C.W. Radar

Although the principles of radar sounding of a medium apply to both pulsed CW and impulse radar systems, there are some basic differences between the two. This first section details these differences.

An impulse radar system generates a very short pulse having a resultant wide bandwidth. The antenna used to transmit the pulse, although designed as a broadband radiator, has a bandwidth which is less than that of the pulse. The result is that the actual pulse transmitted is a triplet waveform having a slightly narrower bandwidth (Figure A.1A).

A pulsed CW radar generates a continuous carried frequency which is turned on and off. The transmitting antenna for the pulsed CW is tuned to the carrier frequency and does not significantly alter the pulse. The pulse shape is shown in Figure A.1B.

The advantage of impulse radar lies in its high resolution capability associated with a low transmission frequency. The individual sections of the triplet are recognizable in the returned signal and this increases the resolution to one third of the resolution calculated from the pulse length alone. The 120 MHz impulse radar system described in this document has an

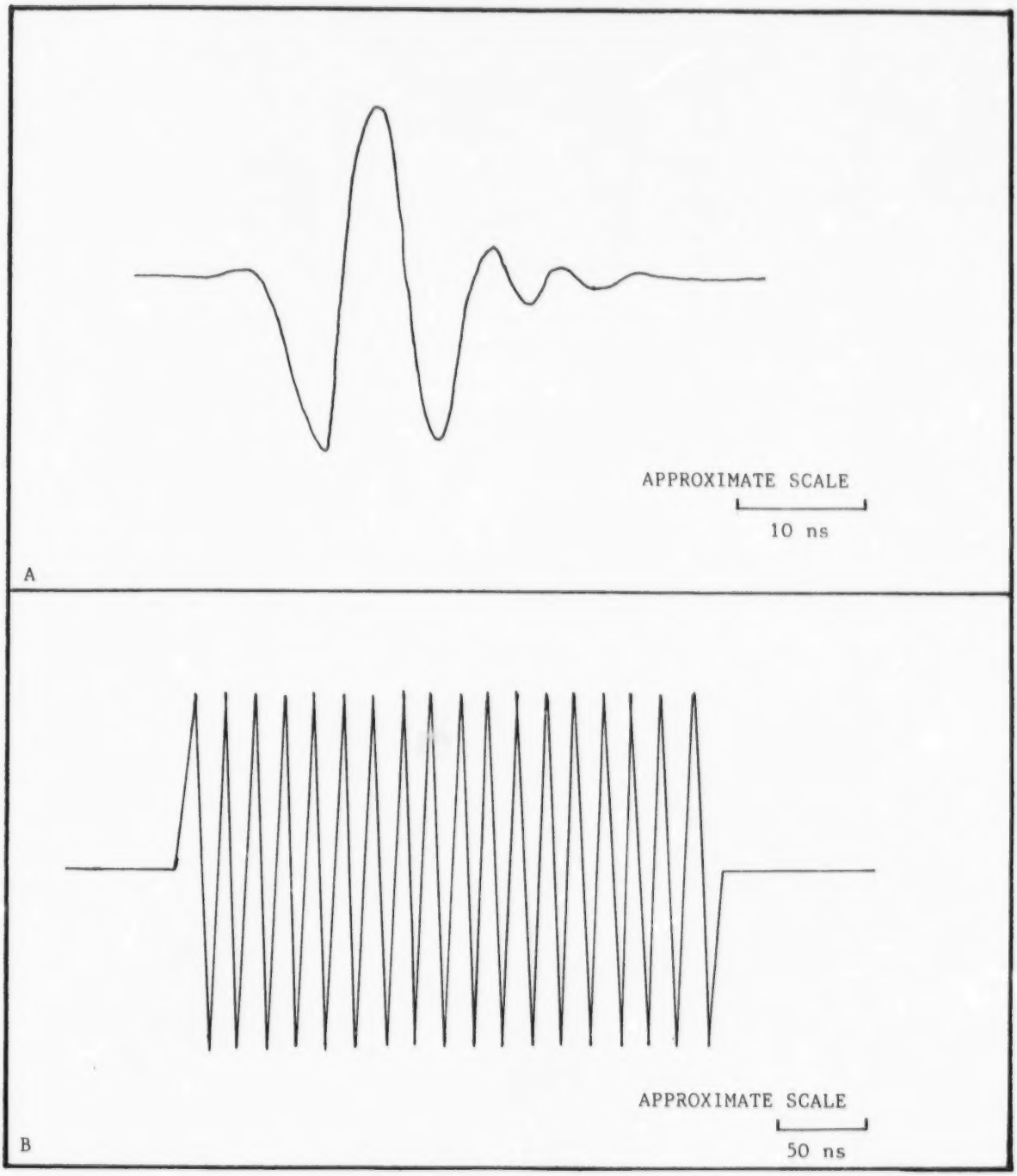



Figure A.1 Comparison of the Transmitted Waveforms From an Impulse and a Pulsed CW Radar

A - Typical Transmitted Impulse From the 120 MHz System with Shielded Antenna.
B - Typical Transmitted Pulse Waveform For 60 MHz Pulsed CW Radar with 300 ns Pulse.

effective time resolution of about 4 nanoseconds. In most materials the signal loss or attenuation rate increases with frequency; impulse radar offers the advantage of a low frequency to maximize penetration capability.

For comparison purposes, to obtain the same effective resolution (4 nanoseconds) of the 120 MHz system with a pulsed CW system, a system bandwidth of 250 MHz is required. Assuming that the bandwidth can be no more than 20 percent of the centre frequency for the pulsed CW system the carrier frequency required will be about 1.25 GHz. The increase in the noise bandwidth (lower receiver sensitivity), exceedingly high power requirements and very high attenuation rates in comparison to those at 120 MHz, would negate any advantage of a higher gain antenna.

It can be seen then that impulse radar has a significant advantage over pulsed-CW radar, particularly in the case of iceberg sounding.

## A.2 Impulse Radar Sounding

The basis of sounding any medium using radar systems is the transmission of electromagnetic energy into the medium and the reception of returned energy from reflecting interfaces. A reflection occurs where there is an abrupt change in the dielectric properties. In order to quantify the reflection process, the dielectric properties of materials are first described. The complex permittivity of a medium ( $\varepsilon^*$ ) which completely describes its dielectric properties is given by:

$$\varepsilon^* = \varepsilon' + i\varepsilon'', \qquad \text{(Eq. A.1)}$$

where $\varepsilon'$ is the real part of the permittivity, and,

$\varepsilon''$ is the imaginary part of the permittivity.

A more commonly used term is the relative permittivity ($\varepsilon_r^*$) defined as the ratio of the absolute permittivity of a medium to the absolute permittivity of free space ( $\varepsilon_o$ ):

$$\varepsilon_r^* = \frac{\varepsilon'}{\varepsilon_o} + \frac{i\varepsilon''}{\varepsilon_o} = \varepsilon'_r + i\varepsilon''r, \qquad \text{(Eq. A.2)}$$

where $\varepsilon'_r$ is the real relative permittivity, also referred to as the dielectric constant, and,

$\varepsilon''_r$ is the imaginary relative permittivity.

The ratio of the imaginary part of the complex permittivity to the real part is referred to as the loss tangent (tan $\delta$ ) and is used to describe the signal losses during propagation. The mathematical expression is:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} = \frac{\varepsilon''_r}{\varepsilon'_r} \quad . \qquad \text{(Eq. A.3)}$$

The velocity of propagation in a medium is given by the expression:

$$v = \frac{2}{\sqrt{\mu_o \varepsilon'}\,\left[\sqrt{(1 + \tan^2\delta)} + 1\right]^{1/2}} \text{ [m/s]}, \qquad \text{(Eq. A.4)}$$

where $\mu_o$ is the absolute permeability of free space.

This expression can be reduced to a more managable form when the loss tangent is small ($\tan \delta < 0.1$), that is when $\varepsilon''_r$ is small compared to $\varepsilon'_r$ . The new expression then is:

$$v = \frac{c}{\sqrt{\varepsilon'_r}} \text{ [m/s]}, \qquad \text{(Eq. A.5)}$$

where v is the propagation velocity, and,
c is the speed of light in free space [m/s].

A more convenient expression for the signal losses is attenuation rate (A), the power loss expressed in decibels per metre, which is related to the loss tangent by

$$A = 1.287 \times 10^{-7} f \sqrt{\varepsilon'_r} \left[ \sqrt{(1 + \tan^2 \delta)} - 1 \right]^{1/2} \text{ [dB/m]} \qquad \text{(Eq. A.6)}$$

where f is the frequency in Hz (centre frequency in impulse radar systems).

Again the expression can be simplified if the loss tangent is small by using (Evans, 1965, Appendix C) the approximation,

$$\left[ \sqrt{(1 + \tan^2 \delta)} - 1 \right]^{1/2} \cong (\tan \delta)/\sqrt{2} \text{ , for } \tan \delta < 0.1,$$

to give: $A \cong 9.0955 \times 10^{-8} f \sqrt{\varepsilon'_r} \tan \delta$ . (Eq. A.7)

The power transmission coefficient for normal incidence, used to quantify the transmission from one dielectric medium into a second dielectric medium, is given by:

$$L_t = \frac{4\sqrt{\varepsilon_2}\sqrt{\varepsilon_1}}{(\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1})^2} \quad , \qquad \text{(Eq. A.8)}$$

where $\varepsilon_1$ is the dielectric constant of the medium in which the wave is incident, and,

$\varepsilon_2$ is the dielectric constant of the medium in which the wave is transmitted.

The power reflection coefficient for normal incidence, used to quantify the reflection at an interface between two dielectric media is given by:

$$L_r = \left(\frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}\right)^2 \qquad \text{(Eq. A.9)}$$

Where $\varepsilon_1$ is the dielectric constant of the medium in which the wave propagates, and,

$\varepsilon_2$ is the dielectric constant of the medium off which the wave is reflected.

To evaluate the ability of impulse radar system to profile a certain medium or detect a given interface, the performance figure of the system is compared to the total power losses in the form of antenna losses and propagation losses experienced in profiling the medium. The equation for the total power loss

(T.P.L.) as given by Morey (1975) is:

$$T.P.L. = 10 \log \left( \frac{(4\pi)^2 [2(h + t)]^2}{\xi_{tx} \cdot \xi_{rx} \cdot G_{tx} \cdot G_{rx} \cdot \lambda_o^2 \cdot L_t^2 \cdot L_r} \right) + 2At \text{ [dB]}, \qquad \text{(Eq. A.10)}$$

where $h$ is the antenna height above the iceberg surface (m),

$t$ is the iceberg thickness (m),

$\xi_{tx}$ is the transmitting antenna efficiency (0.087 for INSTRUMAR System),

$\xi_{rx}$ is the receiving antenna efficiency (equal to in a single antenna system),

$G_{tx}$ is the transmitting antenna gain (1.5 for INSTRUMAR system),

$G_{rx}$ is the receiving antenna gain (equal to $G_{tx}$ in a single antenna system),

$\lambda_o$ is the wavelength in free space (2.5 m at 120 MHz),

$L_t$ is the power transmission coefficient for normal incidence at the first interface (e.g., the air-ice interface) (For two way transmission this term is squared),

$L_r$ is the power reflection coefficient for normal incidence at the second interface (e.g., the ice-water interface), and,

$A$ is the attenuation rate in the medium being profiled (dB/m).

This equation assumes an idealized case of a smooth flat, horizontal reflecting surface. For rough ice surfaces, a more

conservative estimate is given by assuming reflection occurs from the "first Fresnel zone". The revised equation as given by Butt and Gamberg (1979) is:

$$T.P.L. = 10 \log\left(\frac{128\pi^2 (h + t)^3}{\xi_{tx} \cdot \xi_{rx} \cdot G_{tx} \cdot G_{rx} \cdot \lambda o^3 \cdot L_t^2 \cdot L_r}\right) + 2At \text{ [dB]} \qquad \text{(Eq. A.11)}$$

Application of these equations to iceberg profiling has shown that for a tabular berg the equation assuming ideal reflection provides a more reasonable estimate.

## APPENDIX B

## ICEBERG PROFILING: A DELINEATION OF FAVOURABLE AND UNFAVOURABLE CONDITIONS

### B.1 General

The effects of iceberg size, shape, structural features and temperature on the sounding capability of impulse radar are discussed here. A lack of information limits most of the discussions to qualitative assessments.

### B.2 Size

The two extreme size factors to be considered when determining any size limitation for sounding an iceberg are the minimum and maximum limitations. The latter is a limitation determined only by the maximum ice thickness that can be sounded. By theoretical calculation (Appendix A) the upper limit was shown to be 250 metres. If a spherical iceberg is assumed to have this diameter, then the mass of the iceberg would be 7.3 million tonnes. A cubic iceberg with 250 metres as the length of one side would have a mass of 13.9 million tonnes. Therefore, the maximum size that may be sounded successfully would probably have a mass of around 10 million tonnes. This size falls into the large to very large iceberg class which is observed less than 5 percent of the time in the Labrador Sea (Duval, 1975). The minimum size limitation is determined by the size of the iceberg in relation to the radar footprint. The footprint of the impulse

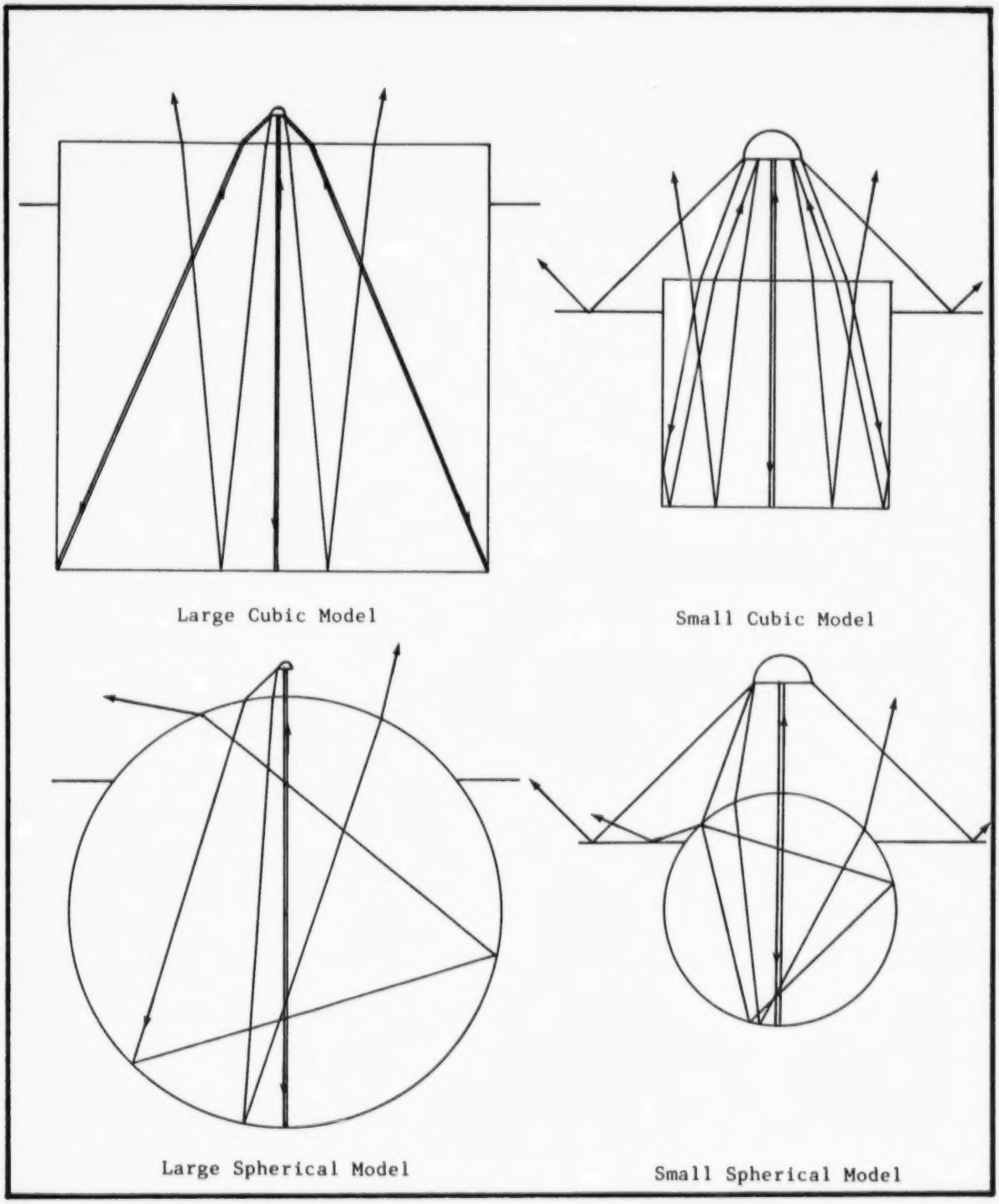



Figure B.1 Diagram of Ray Paths for Cubic and Spherical Iceberg Models.

radar is roughly circular with a radius equal to the height of the antenna (Butt and Gamberg, 1979). If the iceberg is very large in relation to the footprint little or no energy will be returned from the sides of the iceberg when the impulse radar is centred over the iceberg surface. However, if the iceberg is small compared to the footprint then many side reflections can occur. These two extremes are illustrated in Figure B.1.

It can be seen, however, that in the case of the smaller icebergs in Figure B.1 the reflection from any area other than directly below the antenna probably will not return directly to the radar but will be subjected to several reflections. If these signals ever return to the antenna they will be attenuated considerably. Therefore, only if the sides are rough enough and/or oriented correctly, will a sufficient amount of energy be reflected back to the antenna to hide the actual draft echo. The bottom return is reflected back at near-normal angles. It will probably be the strongest return (and in many cases the first return) enabling a draft measurement to be made even when there are side echoes.

It is next to impossible to assign lower limits to the iceberg size based on the preceeding discussion. Rossiter and Gustajtis (1978), however, were able to sound an iceberg with an 18 metre draft successfully, and Rossiter, Narod and Clarke (1979) sounded an iceberg having a draft as little as 28 metres but had side echo problems with a 21 metre draft iceberg. A spherical iceberg with a draft of 30 metres would have a mass of about 24,000 tonnes (a very small iceberg). Icebergs which have

a mass of 24,000 tonnes and may be considered to be the minimum size that can be sounded reliably.

In summary, it is seen that icebergs ranging in mass from 0.024 to 10 million tonnes may be sounded. It is emphasized that these limitations are based on rather simplified iceberg models and very little quantitative information. Only after considerable operational experience will it be possible to identify the limitations confidently.

B.3 Shape

The above surface shape of an iceberg affects the amount of energy penetrating the iceberg, the degree of refraction and the location over which a sounding can occur. Tabular, blocky, and (large) domed icebergs are probably the most favourable shapes for sounding purposes because they maximize the energy penetrated, minimize the effect of refraction and normally provide some flexibility over the area to be sounded. Pinnacle and drydock types present the opposite conditions. In situations where only sharp peaks or ridges can be utilized for sounding the maximum penetration depth will be limited because of the small area into which the energy will be radiated. This minimizes the actual amount of energy penetrating the iceberg. In addition, the very large incidence angles with their associated refractions will result in an excessive number of multiple reflections, which may possibly obscure the actual thickness measurement. The inability to sound over a large portion of the iceberg surface area increases the possibility that the maximum draft of the

iceberg may not be sensed. These effects cannot be assessed quantitatively until some operational verification has been undertaken.

B.4 Structural Features

The structural features that affect profiling are cracks and crevasses in the iceberg. The ability of impulse radar to detect cracks and crevasses in icebergs was described by Kovacs (1977b). The effects of surface cracks are relatively minor; they cause small amplitude signals on the profile of the iceberg. When the cracks are below the surface and filled with seawater they can block the impulse radar signals, because the signal attenuation in seawater is extremely high. In general, a crack could block the radar signals in one area of the iceberg (predominantly near the edges) while in other areas of the berg thickness measurements could be made. Major seawater filled crevasses in the bottom of an iceberg may introduce signals that interfere with the interpretation of the real bottom echo. For large bergs, in which crevasses can be a problem, it should be possible to discriminate between the sharp spike return of a crevasse and the greater horizontal extent of the bottom return.

B.5 Temperature

The effect of temperature on the performance of the impulse radar is twofold. The signal attenuation in the ice increases with increasing temperature thereby decreasing the maximum thickness that can be penetrated (Section 2.2), and the melt

water that forms on the surface of the iceberg when the ice temperature rises, causes increases losses due to reflection. The maximum attenuation was used to calculate the maximum penetration depths (Section 2.5). It is sufficient, therefore, to state that a low temperature represents a conditin more favourable for profiling. The problem of meltwater on the surface is confined to small areas of the iceberg, due to runoff from the iceberg surface, and the problem is expected only on bergs in warm air environments.

# APPENDIX C

## SPECIFICATIONS OF THE INSTRUMAR MODEL 100, 120 MHz AIRBORNE IMPULSE RADAR SYSTEM

# Airborne Impulse Radar

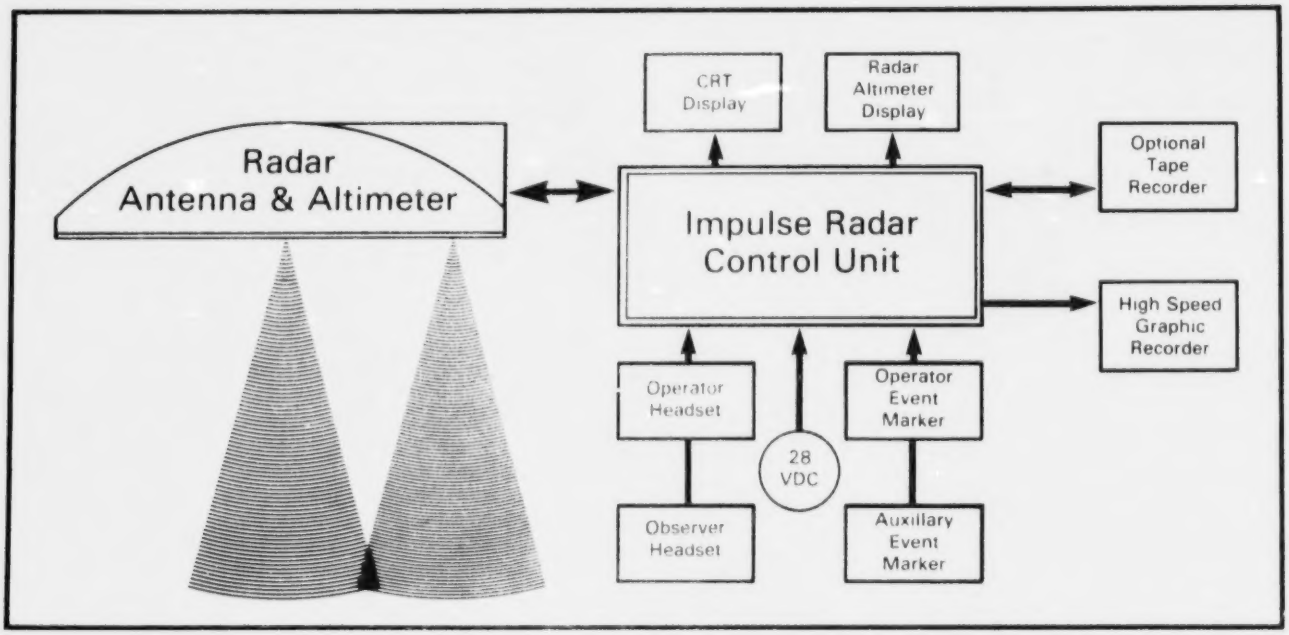
Designed primarily for airborne sea ice thickness profiling, the **INSTRUMAR** Impulse Radar Model 100 can also be used for fresh water ice thickness measurement. The system can be custom configured to suit user requirements for a variety of industrial and scientific applications such as airborne draft measurement of small icebergs or peat bog depth profiling.

The package includes a shielded antenna, M.O.T. approved for "hook" deployment on Bell 206L or B helicopters. Radar control unit, high speed graphic recorder and peripherals are housed within the aircraft. Operator/observer communications are logged on a stereo cassette recorder built into the control unit. A radar altimeter provides operator and pilot with precise height information for controlled low altitude surveys.

- High scan rate (256/sec) provides ice surface coverage of 10 cm/scan at a horizontal velocity of 25 metres/second
- Fixed time window allows precise calibration and reduced operator error
- Time-range measurements in excess of 100 metres of freshwater ice are possible
- Exponential time gain amplification for path loss compensation
- Simplified operator control functions permit easy handling with minimum error
- Shielded antenna reduces systematic noise
- "Four point" antenna mount for ultrastable "hook" installations on Bell 206L and B helicopters
- Microprocessor controlled real time background noise removal


# INSTRUMAR Limited

p.o. box 13246, St. John's, Newfoundland, A1B 4A5, (709) 726-8460, telex 016-4794




MODEL 100 SPECIFICATIONS:

| | |
|---|---|
| Centre Frequency: | 120 MHz |
| Approx. Bandwidth: | 80 to 180 MHz |
| Approx. Pulse Length: | 10 ns |
| Antenna Size: | 148 cm x 120 cm x 36 cm |
| Antenna Deployment: | Transceiver only |
| Antenna Mount: | "hook" deployed frame for Bell 206B and Bell 206L helicopters |
| Performance Figure: | ≈ 115 dB (includes receiver gain) |
| Peak Power: | 50 Watts |
| Scan Rate: | 256 or 64 scans second |
| Range Window: | 90 or 360 ns (can be modified to suit application) |
| Altimeter:* | Display: 3½ digit LCD<br>Range: 45' to 2000'<br>Accuracy: 45' to 100' ± 5%<br>500' to 2000' ± 7% |
| Surface Pulse Altitude Offset Control: | Manual Mode – 0', 50', 100', 200'<br>Auto (altimeter) – 50' to 275' |
| Display: | "A" scope CRT (5 x 3.5 cm) and real time paper chart profiling |
| Dynamic Range: | 66 dB for +3 dB S/N |
| Max. Signal Gain Available after Receiver: | 48 dB (excluding time gain) |
| Max. Time Gain Available after Receiver: | 24 dB |
| Recording: | Synchronous start and stop voice recording on two track cassette<br>Grey level paper chart recorder for in-flight processing<br>Optional analog data logging on 4 channel magnetic tape |
| Power Requirements: | Control module – 100 watts at 28 VDC ± 2 VDC |
| Physical Dimensions (mm): | Control module – 585 x 350 x 340<br>Mini-fax chart recorder – 400 x 254 x 254 |
| Weight: | Control module – 19.00 kg<br>Mini-fax chart recorder – 7.27 kg |

Optional Mag Tape Recorder

| | |
|---|---|
| Power Requirement: | 60 watts at 12 – 30 VDC |
| Dimensions (mm): | 482 x 140 x 432 |
| Weight (kg): | 17 |

*Calibrated in feet compatible with existing North American aircraft systems